Lake Boren Water Quality
Water Quality Monitoring Results for Water Year 2013

March 2014

King County

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Prepared for:
The City of Newcastle

Submitted by:
King County Lakes and Streams Monitoring Group
King County Water and Land Resources Division
Department of Natural Resources and Parks

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OVERVIEW

The King County Lakes and Streams Monitoring Group (KCLSM) and its predecessor, the Lake Stewardship Program, have been working with volunteers to monitor water quality in Lake Boren since 1994, with few gaps in the collected data. Long term water quality data indicate that the lake has fairly good water quality, and currently exhibits moderate algal productivity (mesotrophy).

In 2005, the City of Newcastle began working with King County to fund the monitoring effort in Lake Boren, including the additional monitoring of fecal coliform bacteria. In 2013, a project was started to monitor water quality during storms along China Creek, the main inlet to Lake Boren.

There is a public park at the southwest end of Lake Boren that offers opportunities for fishing along the shore line, as well as from a large dock. The Washington Department of Fish and Wildlife continues to stock the lake each year with approximately 1,000 rainbow trout. Although there is no longer a trailer-accessible public boat launch, the park offers a location to launch small boats along the shoreline. This presents a possibility for the introduction of noxious weeds (non-native species) into the lake.

The lake is known to host a non-native tape grass (*Vallisneria americana*), which does not appear to be causing any major problems. Eurasian watermilfoil (*Myriophyllum spicatum*), defined as a noxious weed by the State of Washington, has also been identified in the lake and should be monitored to avoid contamination of other water bodies. There have been efforts in Lake Boren to control fragrant water lilies (*Nymphaea odorata*) and yellow flag iris (*Iris pseudacorus*).

The discussion in this report focuses on the 2013 water year. Water years run from October through September instead of January through December in order to group sequential wet season months together instead of splitting them between two calendar years. Specific data used to generate the charts in this report can be downloaded from the King County Lakes and Streams Monitoring data website at:

http://your.kingcounty.gov/dnrp/wlr/water-resources/small-lakes/data/default.aspx

Data can also be provided in the form of excel files upon request.

Further introduction and a discussion of the philosophy of the volunteer lake monitoring program and the parameters measured can be found on-line at:

http://your.kingcounty.gov/dnrp/library/archive-documents/wlr/waterres/smlakes/2006_Intro.pdf

1.0 WHAT WE MEASURE AND WHY

Measurements that were taken at all of the lakes in the small lakes monitoring program are discussed in this section to introduce the parameters and give context to the discussions of the data that follow.

Secchi transparency is a common method used to assess and compare water clarity. It is a measure of the water depth at which a black and white disk disappears from view when lowered from the water surface. Level I volunteers measure Secchi depth and water temperature at a station in the middle of the lake weekly throughout the year. Level II volunteers measure 12 times between May and October when they collect water samples for laboratory analysis.

Phosphorus and nitrogen are naturally occurring elements necessary for growth and reproduction in both plants and animals. However, many activities associated with residential development can increase these nutrients in water beyond natural levels. In lakes of the Puget Sound lowlands, phosphorus is often the nutrient in least supply, meaning that biological productivity is most often limited by the amount of available phosphorus. Increases in phosphorus can lead to more frequent and dense algae blooms – a nuisance to residents and lake users, and a potential safety threat if blooms become dominated by cyanobacteria (bluegreen algae) that can produce toxins.

Total phosphorus (TP) and **total nitrogen (TN)** are both measured every time the level II volunteers collect water at the 1m depth. More specific forms of nitrogen and phosphorus are measured twice during the sampling period, when water is collected from 3 depths at the station: 1 m, the middle depth of the water column, and 1 m from the lake bottom. These include nitrate-nitrite, ammonia, and soluble reactive phosphorus, and the data can be used to infer the amount of oxygen present in deep water, as well as the presence of internal loading of nutrients from the sediments back into the lake water.

The **ratio of total nitrogen to total phosphorus (N:P)** can be used to determine if nutrient conditions are favorable for the growth of cyanobacteria (bluegreen algae), which can negatively impact uses of the lake and potentially produce toxins. When N:P ratios are near or below 25, nitrogen is as likely to be the limiting nutrient as phosphorus. Cyanobacteria may then be able to dominate the algal community due to their ability to take up nitrogen from air.

Chlorophyll-*a* concentrations indicate the abundance of phytoplankton in the lake. Although different species of algae contain varying amounts of chlorophyll, all algae use it in order to complete the photosynthetic pathway by which they store energy. For example, some cyanobacteria have other light-catching pigments and thus have relatively little chlorophyll compared to their biovolume.

Pheophytin is a product of chlorophyll decomposition and is generally measured along with chlorophyll as an indicator of how freshness or viability of the sample. Bottom sediments will contain a large amounts of pheophytin compared to chlorophyll, while actively-growing algae from surface waters will have very little pheophytin present.

A common method of tracking water quality trends in lakes is by calculating the **Trophic State Index (TSI)**, developed and first presented by Robert Carlson in a scientific paper dated 1977. TSI values predict the biological productivity of the lake based on three parameters that are easily measured: water clarity (Secchi), total phosphorus, and chlorophyll-*a.* The values are scaled from 0 to 100, which allow them to be used for comparisons of water quality over time and between lakes. If all of the operating assumptions about a lake ecosystem are met, the 3 TSI values should be very close together for a particular lake. When they are far apart in value, lake conditions and measurements should be examined to understand what special conditions exist at the lake or to evaluate the data for errors.

The Index relates to three commonly used categories of productivity:

- *oligotrophic* (low productivity, below 40 on the TSI scale - low in nutrient concentrations, small amount of algae growth);
- *mesotrophic* (moderate productivity, between 40 and 50 on TSI scale – moderate nutrient concentrations, moderate growth of algae growth); and
- *eutrophic* (high productivity, above 50 – high nutrient concentrations, high level of algae growth).

A lake may fall into any of these categories naturally, depending on the conditions in the watershed, climate characteristics, vegetation, and rock and soil types, as well as the shape and volume characteristics of the lake basin. Activities of people, such as land development, sanitary waste systems, and agricultural practices, can also increase productivity, which is known as “cultural eutrophication.”

2.0 PHYSICAL PARAMETERS

City staff collected Secchi transparency and temperature data from early May though late October in Lake Boren. Secchi depth ranged from 1.0 to 5.5 meters (Figure 1). The summer average transparency was 3.4 meters, placing Lake Boren in the middle third for water clarity out of twelve small lakes monitored in 2013. Water clarity gradually decreased from early June through the end of the sampling season (note that the Y-axis is traditionally reversed on Secchi charts to mimic looking into the water from the lake surface). This pattern typically indicates a late-season algae bloom (often of cyanobacteria) that produces cloudy water conditions. Average Secchi depth was shallower than in 2012, and seasonal transparency was more variable. The Secchi measurements from October are the lowest recorded in Lake Boren since 2009, when a similar late-season bloom occurred.

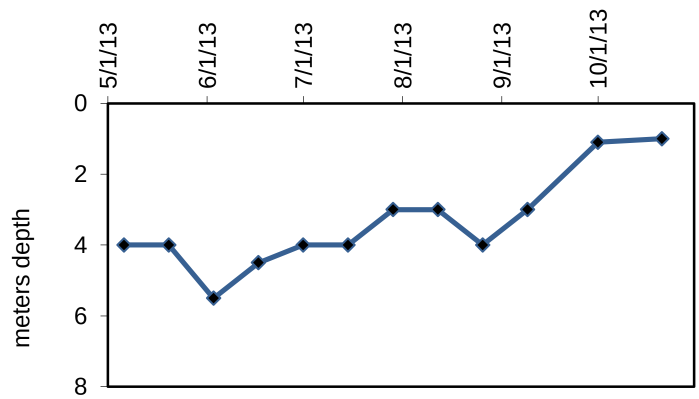

Figure 1. Secchi transparency for Lake Boren, May-Oct 2013.

Water temperatures at 1 m ranged between 12.0 to 25.0 degrees Celsius, with an average of 19.8 °C (Figure 2). Temperature was not measured during the June 3rd sample event because of a thermometer problem. Recorded temperatures warmed through July and remained fairly stable until cooling began in late August, a pattern similar to with other lakes in the Puget Sound lowlands. Compared with measurements from 2012, temperature warmed earlier and remained warmer for a longer period of time.

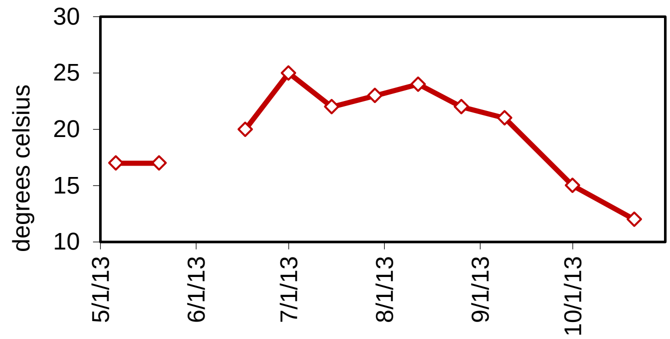

Figure 2. Lake Boren temperature, May-October 2013.

The average May-October temperature in 2013 was notably warmer than the 2012 summer average, and was the highest average temperature recorded since 2009 (Figure 3). This increase reflects the much warmer, drier weather experienced in the Pacific Northwest in 2013. While there is no directional trend occurring in summer water temperatures over time, temperatures appear to reflect annual weather patterns over the period of measurement.

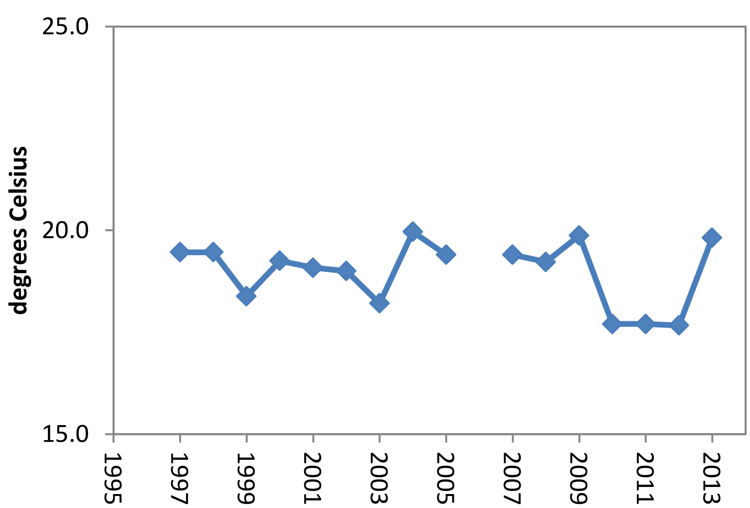

Figure 3. Average summer temperature for Lake Boren, 1997-2013. No measurements were taken in 2006.

3.0 NUTRIENT AND CHLOROPHYLL ANALYSIS

Samples for total phosphorus (TP) and total nitrogen (TN) analyses were collected by city staff at a depth of one meter during the months of May through October. Samples from additional depths were collected on two dates, one in May and another in late August.

Total nitrogen and total phosphorus exhibited differing patterns during the 2013 sample season (Figure 4). Total nitrogen remained stable through late June, decreased in July and remained at that level until mid -September when it began to increase, with the highest TN value measured at the end of the sampling season. Total phosphorus increased slightly throughout the sampling season, with a more dramatic increase occurring in September. These patterns are similar to those that were found last year in Lake Boren.

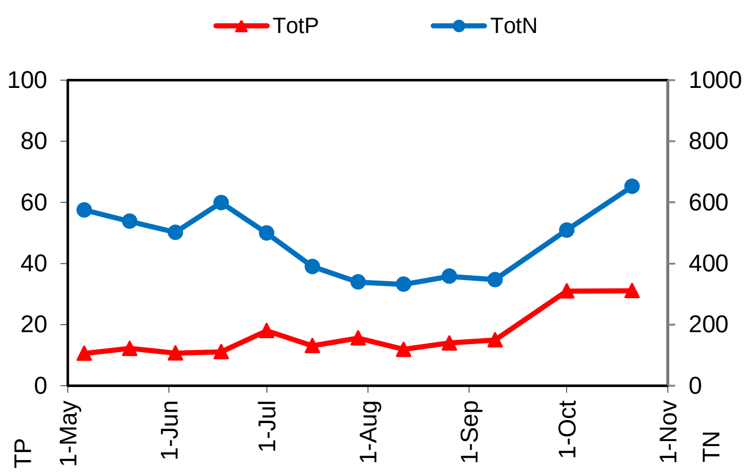

Figure 4. Lake Boren total phosphorus and total nitrogen in µg/L, summer 2013. Note the TN axis is 10x higher than the TP axis.

In 2013, Lake Boren N:P ratios ranged from 16.4-54.2, with an average of 32.7 (Figure 5). Ratios showed a general declining trend throughout the sample season, a pattern similar to that which occurred in 2012. From May-June, ratios remained above the threshold of 25 at which nitrogen may become the limiting nutrient, and cyanobacteria may out-compete other algal species. During the latter portion of the sampling season, ratios remained very near or below this level, which could signify good conditions for the development of cyanobacterial populations.

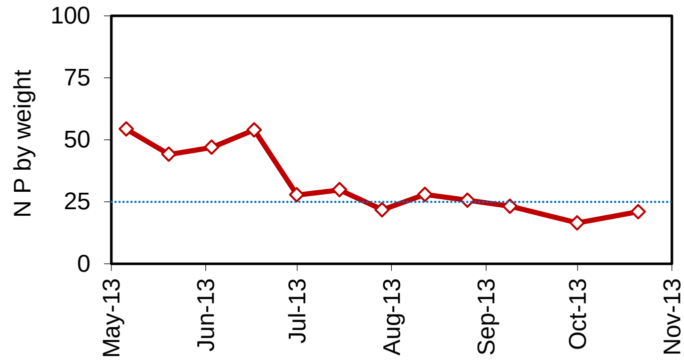

Figure 5. Lake Boren N:P ratios. Values below the blue line indicate a potential nutrient advantage for cyanobacteria.

A sample was submitted on October 14th for analysis to detect the cyanobacterial toxin microcystin. A value of 0.21 ug/L was reported, which showed that microcystin was present, but well below the Washington State provisional recreational guideline of 6 ug/L and therefore not considered to be a health or safety hazard.

Concentrations of chlorophyll-*a* in Lake Boren remained low through August, after which a steady and notable increase persisted through the remainder of the sample season (Figure 6). This pattern is similar to those of past years and is common in lakes that experience late-fall cyanobacteria blooms. Additionally, these results agree with the Secchi transparency data, which also indicated a late season algal bloom. Pheophytin, a degradation product of chlorophyll, was at low detection levels throughout the season.

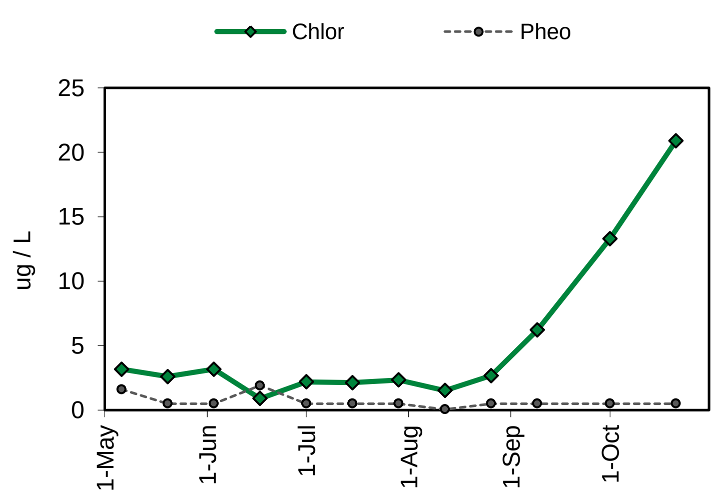

Figure 6. Chlorophyll and pheophytin concentrations for Lake Boren, May-October 2013.

WATER COLUMN PROFILES

Samples were collected at multiple lake depths twice during the sample season (Table 1). Profile temperature data collected in Lake Boren indicate that thermal stratification (temperature layering) was present by early summer and into late August. The deeper water samples had significantly lower temperatures, which suggest that the lake was thermally stratified throughout the summer. There were elevated levels of both ammonia and orthophosphate in the deep sample, which suggested that oxygen was depleted near the bottom of the lake. Anoxia (lack of oxygen) in water facilitates the release of phosphorus from sediments, resulting in higher total phosphorus and orthophosphate (OPO4) values.

Table 1. Lake Boren profile results.

Secchi and Depth in meters. Temperature in degrees Celsius. Chlorophyll and Pheophytin in ug/L. Nitrogen, phosphorus, and alkalinity in mg /L. UV254 is in absorption units. Sample values below minimum detection level (MDL) are marked in **bold, red** font with the MDL value.

Lake name	Date	Secchi	Depth	DegC	Chlor-a	Pheo	Total N	NH3	Total P	OPO4	UV254	Total Alk
Boren	5/20/13	4.0	1	17.0	2.6	0.5	0.538	0.030	0.0122	**0.0020**	0.144	59.3
Boren			5	10.0	4.9	**2.52**	0.562		0.0150			
Boren			9	7.0	2.4	**0.5**	0.807	0.094	0.0227	0.0026		
Boren	8/26/13	4.0	1	22.0	2.7	**0.5**	0.358	**0.006**	0.0140	**0.0013**	0.116	61.4
Boren			5	20.0	7.1	0.5	0.345		0.0154			
Boren			9	7.2	6.6	5.71	1.480	1.060	0.3860	0.1030		

Chlorophyll-*a* profile data indicate that algae are present throughout the water column, but at somewhat higher concentrations at mid-depth than at the surface. The highest concentrations of algae occurred at the 5 meter depth for both sample dates. These values suggest that enough light was reaching deeper water to stimulate algal growth, or that algal species able to adapt to lower light levels were able to take advantage of higher nutrient concentrations in deeper water.

UV254 is the wavelength at which most organic compounds absorb light, and is used to measure the amount of organic compounds coloring lake water. The low values for UV254 indicate that the water of the lake is relatively clear, with a very small amount of coloration from dissolved organic substances.

Total alkalinity is the water's capacity to resist changes in pH or the ability to neutralize acid. Total alkalinity values for Lake Boren show that the water in the lake is less soft than other regional lakes located in undeveloped watersheds, and therefore has more buffering capacity against changes in pH.

4.0 TROPHIC STATE INDEX RATINGS

In 2013 all three TSI values remained in the mesotrophic range (Figure 7), slightly higher than in 2012. Since 2007, the TSI values have stayed similar in value to each other, while varying slightly from year to year.

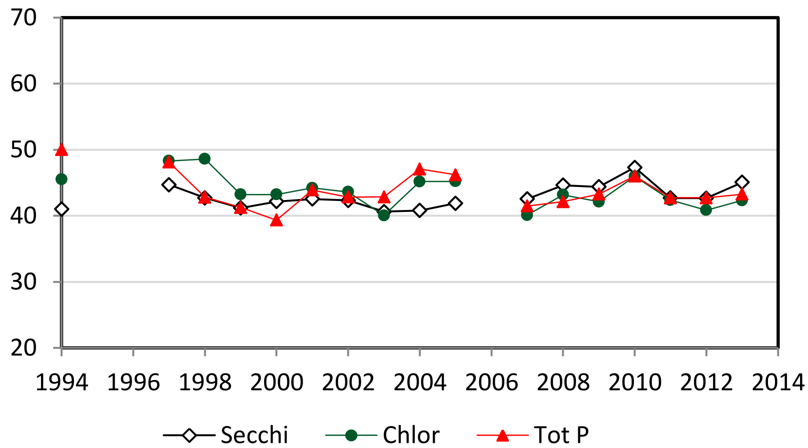

Figure 7. Lake Boren Trophic State Indicators over time.

While there have been fluctuations in all three TSI values over time, in general no increasing or decreasing trend has emerged. When a linear regression trend line is applied to the average of the three TSI values over time, virtually no change is visible (Figure 8).

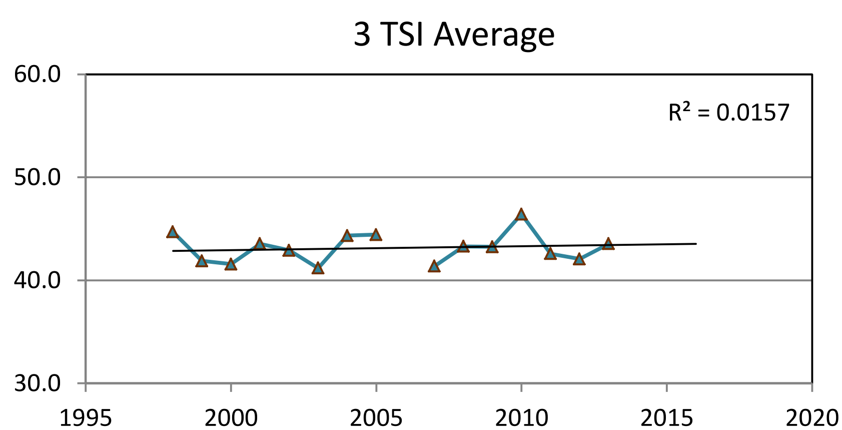

Figure 8. Averages of TSI values for phosphorus, Secchi transparency, and chlorophyll-a over time for Lake Boren.

5.0 *E.COLI* DATA – LAKE BOREN

King County WLRD has monitored the bacterium *E.coli* (*Eschereschia coli*) in Lake Boren from mid-summer through fall since 2005. This year (2013) was the eighth year of monitoring (2006 was missed), with samples collected around the lake on four occasions from July through October.

The lake shoreline includes private residences along the west and northern shorelines, a public park on the southwest side, and open space along the expanded Coal Creek Parkway on the east. On the east shoreline, an abandoned Washington Department of Fish and Wildlife (WDFW) boat launch and former housing sites are reverting to vegetation, with a few remaining concrete structures.

Lake users are very interested in fecal bacteria concentrations in water because they can be indicators of potential pathogens and exposure through water contact and can cause health problems for humans and other warm-blooded animals. There are several standards in use for categorizing risk associated with human exposure to fecal coliform bacteria.

The Environmental Protection Agency (EPA) considers the fresh water concentration of *E. coli* to be a relatively good predictor of potential exposure to pathogens, and they identify a geomean of 126 cfu/ 100 ml (colony forming units per 100 milliliters of water) as the water quality standard. However, total fecal coliform bacteria, which include several species in addition to E. coli, have been historically used by Washington State to set standards for freshwater quality. For lakes without special exceptions, the standard for lakes in Washington is currently defined under WAC 173-201A-600 as a geometric mean of 50 cfu/ 100 ml, with no more than 10% of the individual samples exceeding 100 cfu/100 ml.

Since *E. coli* can move freely through the water, results may be quite variable between sites and sample dates. Quite often water from a particular station can produce a high *E. coli* count on one date, but be below detection levels the next. Because of this, it is important to sample stations repeatedly to look for general patterns over time.

While single values somewhat higher than 100 cfu/100ml might not indicate a major health risk or significant bacterial pollution, repeated values over 100 cfu/100ml are likely to represent an ongoing source of fecal contamination that can potentially impact primary contact recreation uses of the water. It is important to note that this threshold is a guideline used to gauge relative risk and potential point sources, so single values exceeding 100 cfu/100ml should not trigger swimming restrictions or regulatory actions.

In developed watersheds such as Lake Boren, there are several possible sources of fecal coliform bacteria, both human and non-human in origin. Waste from domesticated animals can be a major source of fecal bacteria, including *E. coli*, especially when livestock or pet waste is not collected and disposed of properly. Beavers, rats, geese, ducks and other warm-blooded animals can also constitute major sources of *E. coli* bacteria. These nondomesticated or “wild” animal sources may not affect human health risk and can also be much harder to control.

Possible human sources of bacteria include illegal and/or inadvertent sanitary sewer connections to storm drains, cracked or broken sewage influent conduits, illegal dumping to storm drains, failing septic systems, and occupied areas with no sanitary facilities such as transient camps. Septic systems need regular maintenance to operate effectively, but homeowners are sometimes unaware of the necessary frequency, and there may be no legal mandates that allow for stricter regulation.

Methods

Comprehensive *E. coli* screening studies can become very expensive when the samples are sent to an EPA accredited lab for analysis. The study of Lake Boren bacteria has consistently used the Coliscan Easygel method (see previous reports for description), which is inexpensive and accurate enough for producing a data set that describes the general situation for a body of water.

Locations and schedule

Samples were collected once a month in 2013, July 10th, August 19th, September 17th, and October 14th. Duplicate samples were collected at two to four randomly-chosen stations during each sampling event in order to provide quality control and assurance.

Station locations were originally randomly selected along the shoreline in 2005, but have evolved over time to include sampling sites near locations that have produced high values over the years. The same stations that were sampled in 2012 were targeted again in 2013 (Figure 9).

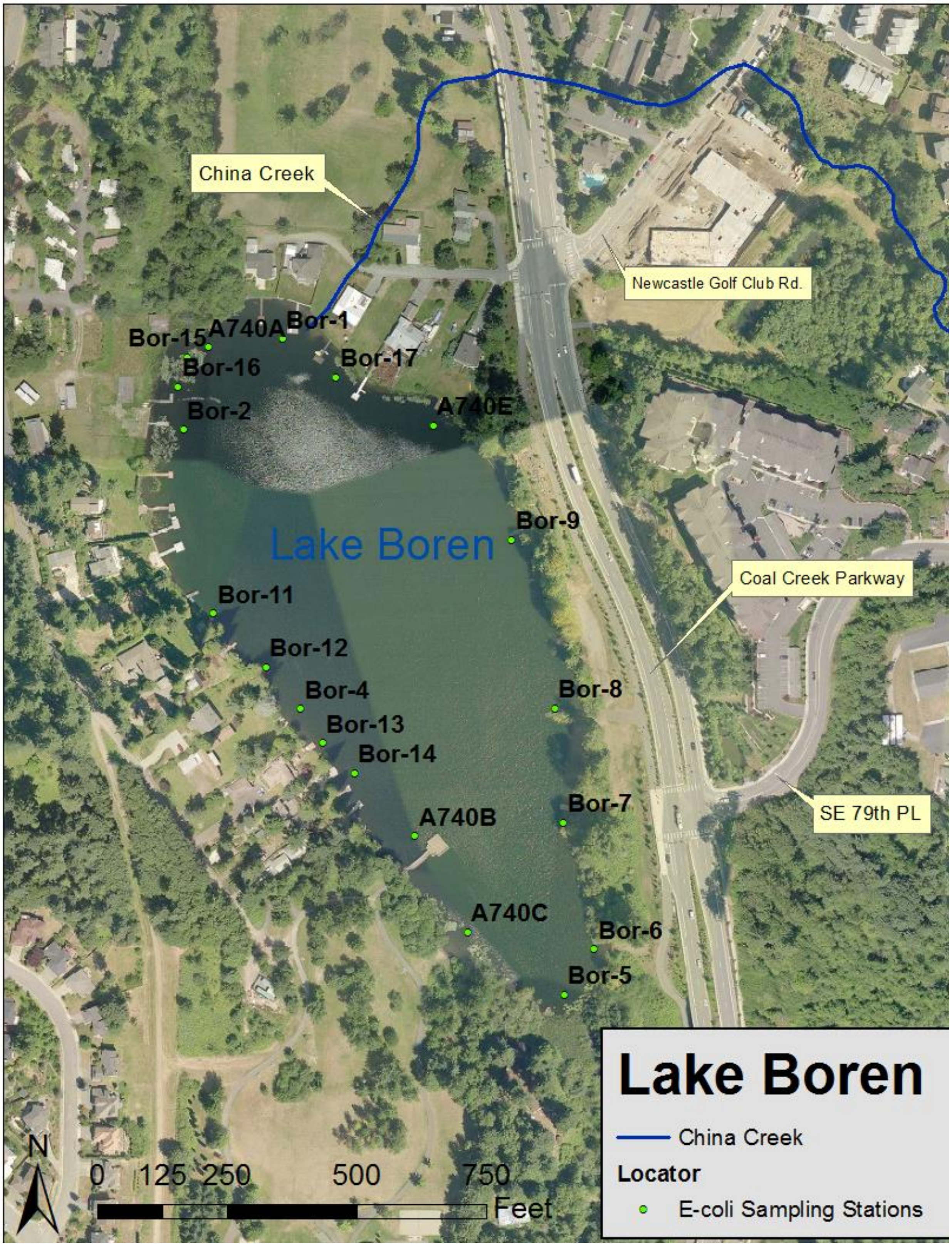

Figure 9. Map of Lake Boren with locations of 2012 – 2013 sampling sites.

Results and Discussion

All of the 2013 Boren Lake samples were taken at least 2 days after any rain was recorded, and most of them after at least a week of dry weather. This suggests that most of the detected *E. coli* were not entering the lake through stormwater events.

As in previous years, the majority of the samples taken along the lake shore tested low for *E. coli* concentration (Table 2). While five stations had samples that exceeded 100 cfu/100 ml at least once during the season only two sites exceeded the state fecal coliform threshold of a geomean higher than 50 cfu/100 ml for the year (Bor17). Because only four samples were taken during the season, any datum exceeding the threshold of 100 cfu / 100 mL would automatically violate the second half of the standard by having more than 10% of the samples above the threshold.

Table 2. 2013 E. coli concentrations at Lake Boren . Values are expressed as colony forming units per 100 mL. Values exceeding 100 cfu/100 mL are highlighted in yellow. Geomeans higher than 50 are highlighted in orange. Minimum detection level is 1 cfu / 100 mls and must be used to calculate geomeans.

Sample Sites	7/10/2013	8/19/2013	9/17/2013	10/14/2013	geomean	% occurrence >100
Bor1	40	30	30	20	29.1	0
Bor2	1	40	40	20	13.4	0
Bor4	40	20	60	20	31.3	0
Bor5	200	100	40	20	63.2	50%
Bor6	100	1	1	20	6.7	25%
Bor7	1	20	1	60	5.9	0
Bor8	1	40	1	1	2.5	0
Bor9	1	1	1	1	1.0	0
Bor11	60	1	40	1	7.0	0
Bor12	60	1	20	30	13.8	0
Bor13	80	1	20		11.7	0
Bor14	60	1	1	1	2.8	0
Bor 15	1	1	40	20	5.3	0
Bor16	60	20	1	20	12.4	0
Bor17	830	20		20	69.2	25%
A740A	100	1	1	60	8.8	25%
A740B	10	20		20	15.9	0
A740C	260	60	1	40	28.1	25%
A740E	1	1	40	1	2.5	0

The stations with values over 100 cfu/100 ml are located in areas that have historically had higher E. coli values. Station Bor17 east of the inlet from China Creek had the highest geomean of the sites sampled in 2013 at 69 cfu/100 mls, probably related to the one very high individual value of 840 cfu/100 mls. Station A740A is also at the north, off the recent development site and among water lilies. Station 740C is at the small park beach by the dock. Stations Bor-5 is at the outlet at the south end, while station Bor-6 is nearby at the old boat launch site. All of these site locations have factors that affect the data, for example proximity to human and animal activities.

It should be noted that the delta building off shore from the China Creek inlet often has waterfowl present during sampling events. The north end of the lake also has an infestation of fragrant water lilies along an area that has recently been developed. Water lilies and human activity along shorelines attract water fowl for feeding (potentially increasing fecal inputs). Lilies also can reduce wave action and cause stagnant conditions that allow bacteria to remain longer.

A740C is located along the beach portion of the city park that is known to be used by both waterfowl and dogs. Citizens often use this spot for playing with their dogs, and the spot can also be used for launching car top boats. Isolated high hits may be attributable to occasional animal waste.

Through the entire series of data collection between 2005 and 2013, 23 stations have been sampled around the lake, with 19 stations continuing to be monitored in 2013 (Table 3).

Table 3. 2005-2012 E. coli sampling throughout the study. Stations with more than 10% occurrences above 100 are highlighted in yellow.

Sample Sites	period of sampling	#samples	Geomean	CFU > 100	% occurrence
A740	2005 only	5	3.4	0	0.0%
Bor3	2005 - 2011	26	5.8	1	3.8%
Bor10	2005 - 2011	26	3.2	3	11.5%
A740D	2005 - 2011	25	2.5	0	0.0%
Bor1	2005 - 2013	33	8.5	4	12.1%
Bor2	2005 - 2013	34	7.0	2	5.9%
Bor4	2005 - 2013	34	14.8	5	14.7%
Bor5	2005 - 2013	34	15.6	3	8.8%
Bor6	2005 - 2013	34	8.4	2	5.9%
Bor7	2005 - 2013	34	4.6	1	2.9%
Bor8	2005 - 2013	34	3.7	1	2.9%
Bor9	2005 - 2013	34	4.2	0	0.0%
A740A	2005 - 2013	34	7.6	2	5.9%
A740B	2005 - 2013	33	7.4	0	0.0%
A740C	2005 - 2013	35	27.7	9	25.7%
A740E	2007 - 2013	28	2.6	0	0.0%
Bor11	2008 - 2013	25	7.8	0	0.0%
Bor12	2008 - 2013	20	8.7	1	5.0%
Bor13	2008 - 2013	19	22.9	1	5.3%
Bor14	2008 - 2013	20	5.9	2	10.0%
Bor 15	2012 - 2013	8	13.2	1	12.5%
Bor16	2012 - 2013	8	7.5	0	0.0%
Bor17	2012 - 2013	7	28.7	1	14.3%

When averaged over all data collected for each station, no site has produced a geomean above 50. However, seven stations could currently be in violation of the criterion of more than 10% above 100 cfu/100 mL , including Bor1, Bor4, Bor10, Bor14, Bor15, Bor17, and A740C . Of these, A740C has had the most violations, which have occurred in 5 out of the 8 years. This may be linked to both beach use by dogs and their owners and by waterfowl concentrated at the open shoreline. Bor10, which was dropped at the end of 2011, was last found to exceed 100 cfu/100 mls in 2008 and may no longer have an issue. Six of the 7 locations with greater than 10% high values were sampled in 2013 and will be targeted again in 2014.

6.0 *E. COLI* DATA – CHINA CREEK

In August of 2012 King County staff began monitoring *E. coli* in China Creek for the City of Newcastle. This effort was initiated because elevated values of bacteria in the lake were recorded near the China Creek inflow to Lake Boren, and it was possible that the bacteria were coming into the lake from the creek . Results from 2012 suggested violations of bacterial standards at certain sites, so *E. coli* evaluation was included with stormwater sampling in 2013. The sampling stations remained the same as 2012 (Figure 10). Two storm events were sampled on March 20th and November 7th in 2013.

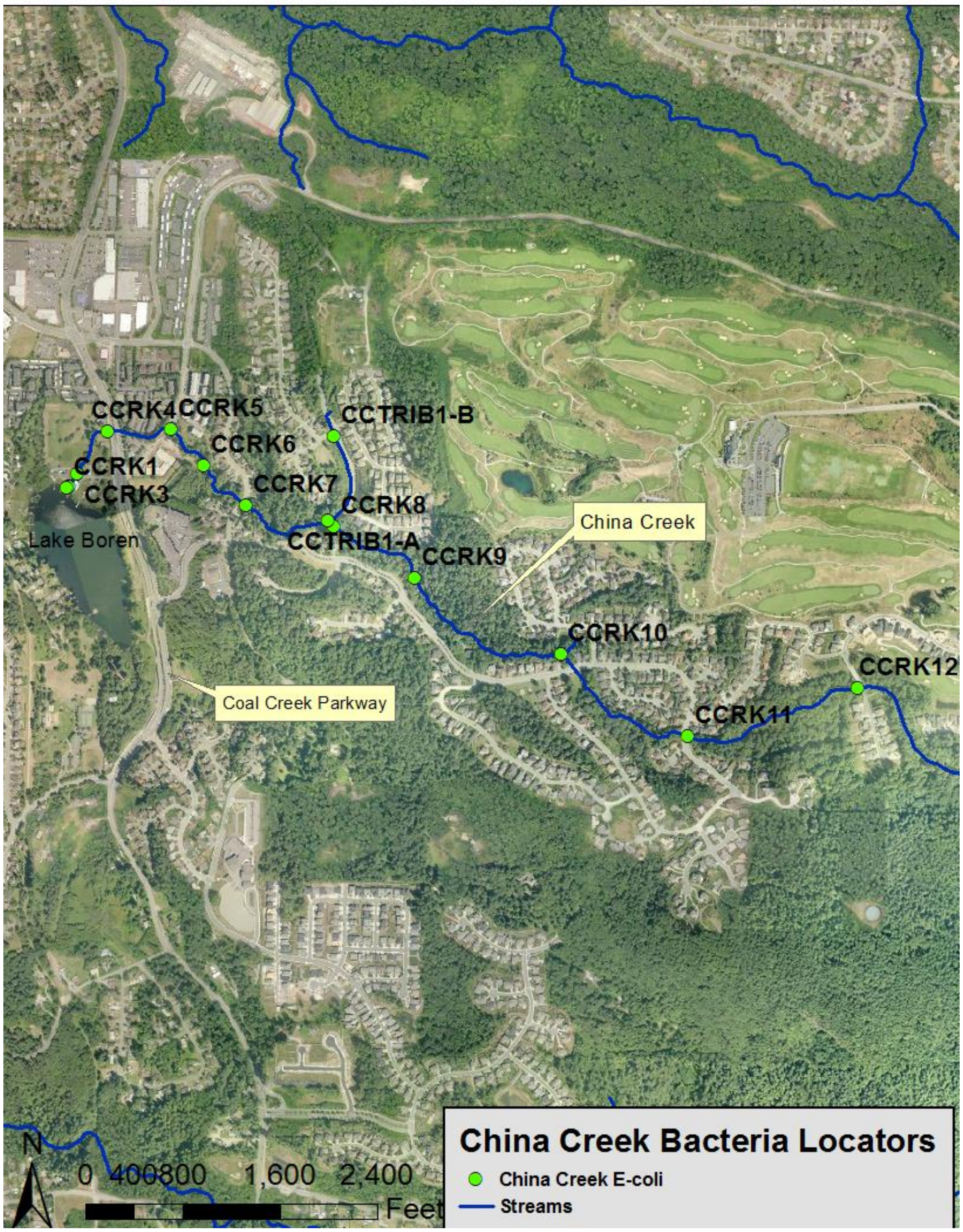

Figure 10. Map of 2012-2013 China Creek Sampling Locations.

The Sept 11th 2012 was dry, with no rainfall of note preceding sampling (Table 4), while the December3rd, 2012 event was wet, with a large event 3 days previously that were followed by steady rainfall up until and including the time of sampling. Both of the sampling events during 2013 were wet weather samples with preceding dry periods, but the November sample event in particular appears as if it may have been during a first flush of runoff.

Table 4. Rainfall record from nearby gauge for dates of sampling

Rainfall	9/11/2012	12/3/2012	3/20/2013	11/7/2013
3 days before	0.00	1.08	0.00	0.01
2 days before	0.00	0.30	0.00	0.11
previous day	0.07	0.80	0.26	0.08
sample date	0.00	0.53	0.57	1.20

The data from the dry September 2012 date were in general higher than those taken after days of rain later on in December (Table 5). In contrast, both storm events in 2013 produced higher values than found in 2012, particularly in November. This could be due to: (1) direct seasonal effects due to temperature differences and degree of saturation of the soils; or (2) the timing of grab sampling in relation to the storm trajectories and rain accumulation in the days previous to each event.

Table 5. China Creek E. coli results 2012 – 2013. Precipitation status is indicated at the top of the chart, based on Table 4..

rain status	dry	dry	storm	storm	first flush
Stations	**8/16/2012**	**9/11/2012**	**12/3/2012**	**3/20/2013**	**11/7/2013**
CCRK13			40	0	1120
CCRK12		160	60	40	1140
CCRK11		100		140	2460
CCRK10A		160	120		
CCRK10			20	300	1620
CCRK9		70		760	1820
CCRK8		220	120		1620
CCRK7		200	180	580	1120
CCRK6		140	160		1060
CCRK5		340	90	650	1450
CCRK4		160	20	520	1300
CCRK3	430	220			1420
CCRK2	640	220			
CCRK1	500	280	80		

During the 2013 storm sampling, all but the 3 upper stations during April likely exceeded the state standard for total fecal coliform bacteria; the data collected in November are uniformly very high. It should be remembered that our samples were evaluated for *E.coli*, using the Coliscan Easygel method, rather than for total fecal coliform bacteria as called for by the state standards. However, *E.coli* is one of several fecal coliform bacteria species and values generally correlate well with total fecal coliform bacteria. Therefore, the data indicate that there are times when fecal coliform bacteria are at high concentrations in the creek.

7.0 CHINA CREEK STORM SAMPLING

In 2013 the City of Newcastle contracted with King County Lakes and Streams Group to collect water quality data on China Creek, which is the primary inlet to Lake Boren. Two sampling events were conducted during 2013. Both were carried out during storms and consisted of grab samples at eight locations along the creek (Figure 11). The first sampling event took place on 3/20/2013, and the second on 11/7/2013.

Figure 11. Location of sampling sites for water quality along China Creek in the City of Newcastle.

Precipitation measurements taken at a nearby King County rain gauge on Lower May Creek (station 37u) show that both events had similar cumulative precipitation levels but the 11/7/2013 event was taken just after the peak intensity of the storm while the 3/20/2013 sample was taken during a moderate, but consistent rainfall event (Figure 12).

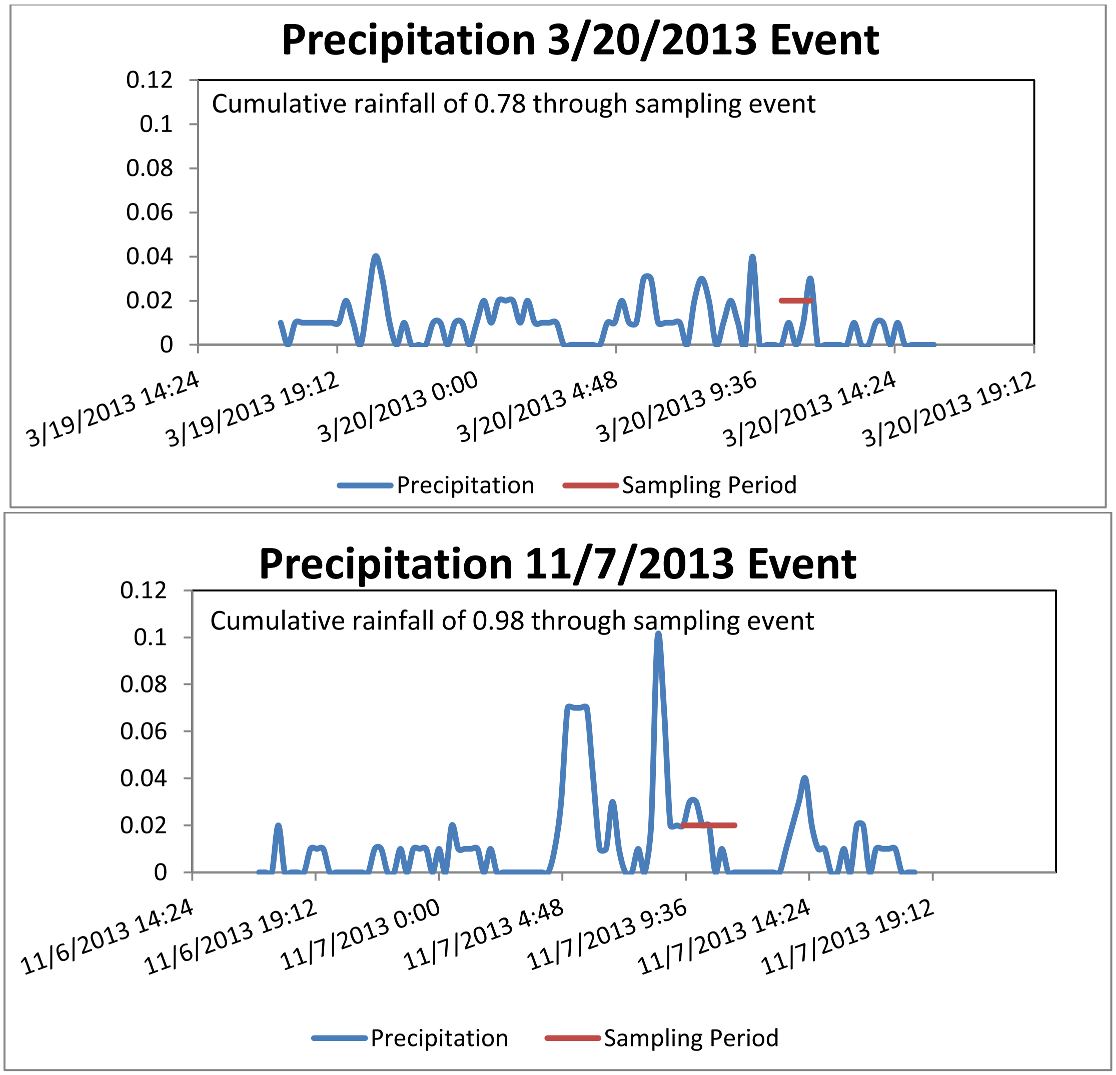

Figure 12. Precipitation record from KC station 37u on May Creek, with grab sample collection period superimposed as a red line on the rainfall record.

Water was collected at the stations for *E. coli* bacteria, total suspended solids (TSS) and nutrients, including total phosphorus (TP), total nitrogen (TN), ammonia nitrogen (NH3), and orthophosphate (OPO4) Results are presented in Table 6.

Because this was the first year of sampling for nutrients at sites along China Creek, trends for water quality cannot be evaluated. In addition, there are currently no Washington State Water Quality Standards for nutrients or suspended sediments, so comparisons cannot be made against regional standards.

Table 6. Water quality results for grab samples taken along China Creek during two storm events in 2013. All data are in mg/L except for *E.coli*, which are expressed as colony-forming units per 100 mls. Numbers in bold red font represent values below the minimum detection limit and are represented by the detection limit for that analysis. Stations go from upstream to downstream in order.

	Total P mg/L		OPO4 mg/L		Total N mg/L		NH3 mg/L		TSS mg/L	
Locator	3/20/13	11/7/13	3/20/13	11/7/13	3/20/13	11/7/13	3/20/13	11/7/13	3/20/13	11/7/13
CCRK13	0.0089	0.1240	0.0043	0.0041	1.360	1.230	**0.005**	0.015	20.4	7.6
CCRK12	0.0612	0.1220	0.0080	0.0171	0.828	1.610	0.010	0.038	18.4	25.6
CCRK11	0.0251	0.0894	0.0088	0.0267	0.405	0.689	0.013	0.021	9.6	16.8
CCRK10	0.0545	0.0840	0.0108	0.0286	0.676	0.751	0.032	0.023	22	17.6
CCRK9	0.0531	0.2530	0.0108	0.0270	0.743	1.700	0.013	0.013	17.2	54.8
CCRK7	0.0526	0.1110	0.0097	0.0252	0.777	1.230	0.014	0.012	17.4	35.0
CCRK5	0.0485	0.1100	0.0086	0.0243	0.746	1.240	0.015	0.013	14.6	38.0
CCRK4	0.0464	0.1060	0.0084	0.0229	0.712	1.140	0.017	0.012	13.9	33.0

Graphs of the nutrients measured in China Creek appear similar to other northwest stream systems (Figure 13). Studies conducted by Mike Brett and Chris May at the University of Washington show an increase of total phosphorus in relation to orthophosphate during increased flows caused by storm events. The same appears to be true for total nitrogen in relationship to ammonia.

The data also indicate substantial increases in total phosphorus, total nitrogen, and TSS between location CCRK 10 and CCRK 9 during the 11/7/2013 event, which then decrease at the next station downstream, CCRK7. This could be due to specific inputs located along this portion of the creek or actively eroding stream banks between CCRK10 and CCRK9.

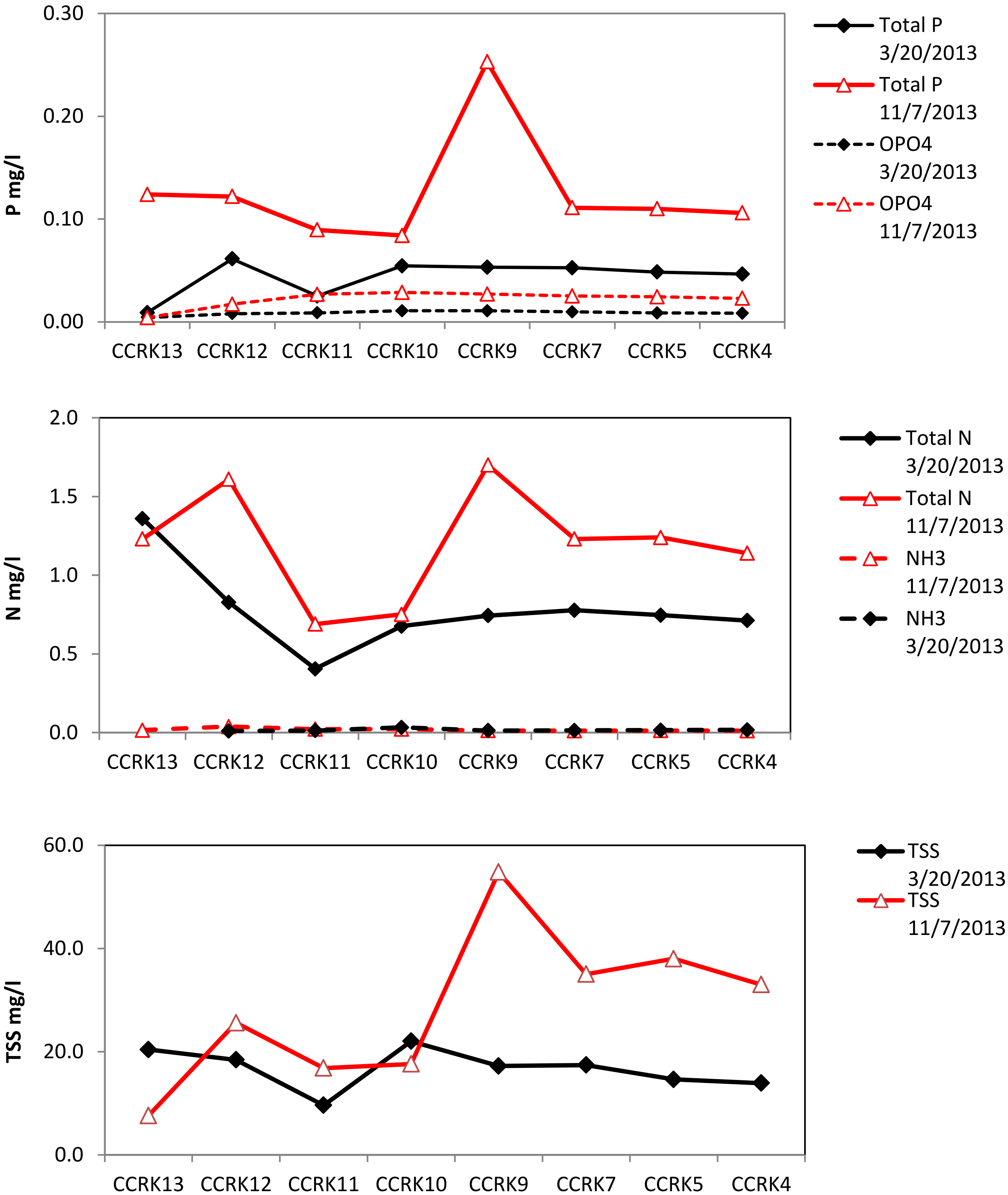

Figure 13. Graphs of nutrients and total suspended solids for 2013 sampling events. Data go from upstream to downstream, left to right.

Precipitation intensity may contribute to differences between dates for nutrient and TSS values collected at the stations. Averages of the data collected at all stations for each parameter from the November event were higher than for the March event, which could be the result of greater rainfall mobilizing more sediment and associated nutrients all the way along the creek (Table 7)

Table 7. Comparison between sample dates of mean values for all sites for each measured parameter. All values in mg/L except E. coli, which is expressed as colony-forming units per 100 mls.

	3/20/13	11/7/13	% diff
NH3-N	0.015	0.018	123%
Total N	0.781	1.199	154%
OPO4	0.0087	0.0220	254%
Total P	0.0438	0.1249	285%
TSS	16.7	28.6	171%
E-coli	374	1504	402%

While the water quality sampling of China Creek is currently limited to 2013, we can make comparisons with data collected during wet weather at other regional streams. May Creek, Tibbetts Creek, and Lewis Creeks were selected because they have extensive data sets and have been routinely monitored by King County (Figure 14) . These creeks have more discharge than China Creek, but all are located nearby and are close enough to be influenced by similar precipitation patterns and geology. Land cover/land use and size of the contributing watersheds vary. China Creek is actually a tributary to May Creek through Lake Boren.

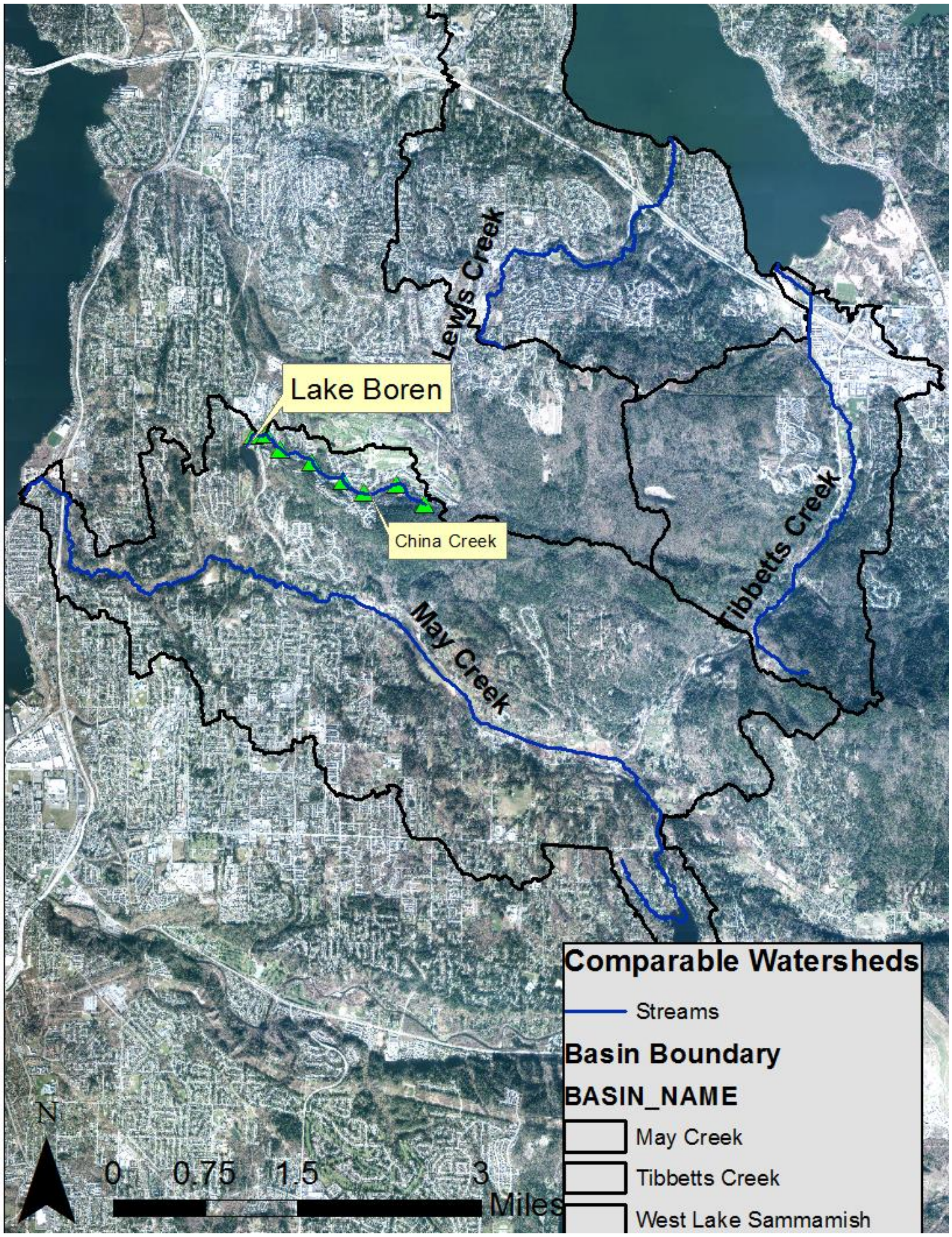

Figure 14. Map showing location and watershed of comparison streams. China Creek stormwater stations are marked by green triangles in the May Creek drainage.

Wet weather data from each of the creeks taken between October and March from 2013 and 2014 were included (Table 8). These data may not directly represent storm samples, but can be used to characterize winter water quality conditions. For each creek, the monitoring station is located near the mouth, so only the lowermost station (CCRK 4) on China Creek was used for comparison.

Table 8. Average 2013 values from the lowermost station on China Creek compared to data from other local streams on similar dates. All values in mg/L.

Locator/Stream	# Samples	Tot P	TSS	Total N	NH3	OPO4
A617 (Lewis Creek)	6	0.0378	1.45	0.940	0.008	0.0288
X630 (Tibbetts Creek)	5	0.0365	3.42	1.429	0.059	0.0158
440 (May Creek)	10	0.0487	13.78	1.163	0.012	0.0183
CCRK4 (China Creek)	2	0.0762	23.45	0.926	0.014	0.0156

The data show that China Creek is higher in total phosphorus and total suspended solids than the other creeks, while in the lower or midrange for total nitrogen, ammonia, and orthophosphate. The higher TSS and TP averages probably reflect the storm conditions during which China Creek was sampled, as increases in TSS and phosphorus are known to be correlated with increased flows due to erosion.

8.0 CONCLUSIONS AND RECOMMENDATIONS

Lake water quality
Based on monitoring data, water quality in Lake Boren has fluctuated over the sampling years of 1994-2013, similar to the behavior of most aquatic systems responding to multiple and diverse environmental variables. Measurements of physical and chemical parameters have shown both upward and downward variations from year to year.

Results from Secchi depth, chlorophyll-*a,* and N:P analyses indicate the potential for cyanobacteria blooms in Lake Boren. While many species of blue-green algae do not produce poisonous level of toxins, care should be taken if film or scum is observed in the lake. If cyanobacterial blooms are observed, participation in the Washington State Department of Ecology's Toxic Algae Monitoring program is recommended to determine if algae in the lake are occasionally producing toxins.

Continued monitoring of Lake Boren will allow for statistically robust determination of long term trends, as well as providing opportunities to identify potentially detrimental changes occurring in the lake.

E.coli in Lake Boren
While no station has a geomean of greater than 50 when averaged over the entire period of sampling, 7 stations may be exceeding the Washington State standard of no more than 10% of the samples may be above 100 cfu/100 mL. The station with the most exceedances over time is the site at the park beach, which may be due to dogs playing with their owners or to waterfowl gathering on the open shoreline. Most of the sites that may be in violation were sampled in 2013 and will be targeted again in 2014. One sample exceeding the criterion was last above 100 cfu/100 mL in 2008 and may be a location that no longer is producing problems.

E.coli in China Creek
Because of the variability between 2012 and 2013, as well as the differing rainfall patterns, at least one more non- storm event should be measured in 2014 in addition to storm sampling. Also, walking portions of the channel during the dry season to map possible point-source inputs to the creek, such as retention/detention pond outfalls, stormwater runoff pathways or significant sediment sources, should lead to determining ways to isolate bacterial hotspots and move towards the goal of reducing bacterial loading to the lake.

Stormwater quality in China Creek
As more data on storms are collected in China Creek, it is anticipated that recognizable patterns in water quality will emerge, and that in time could be tested for directional trends. The data collected in 2013 compared to nearby streams suggests that China Creek seems to be producing higher total phosphorus and total suspended solids during storms.

Further investigation could be carried out by walking the stream corridor during a low flow period to determine probable sources for the substantial increase in nutrients and suspended solids between CCRK9 and CCRK10 found during the November 7, 2013 storm.